On the applicability of real time stability monitoring for increasing the safety of fishing vessels

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ABSTRACT

Stability-related accidents are among the main sources of fatalities within fishing, and crew lack of training, together with the absence of simple stability-related guidance onboard, have been stated as their main cause. Simplified guidance systems have been proposed as a possible solution to this problem. The authors have developed their own alternative, based on the linking of a stability guidance system with a methodology for estimating the vessel *GM*. In this work, the performance of this method, based on the analysis of the roll motion, will be tested during a fishing campaign onboard a mid-sized trawler, showing very promising results.

Keywords: *Fishing vessels, intact stability, stability monitoring, guidance systems, sea trials.*

1. INTRODUCTION

Fishing is well known for being one of the most dangerous industrial sectors in many countries. One of the main causes of a large percentage of the casualties occurring in fishing are stability related accidents, which in many occasions lead to the capsizing of the vessel (Jensen et al., 2014). It is generally accepted that one of the main causes for this large accident rate is the crew lack of training in stability matters, together with the absence of objective information which could contribute to a proper evaluation of the stability-related risk.

The use of simplified stability guidance systems has been proposed by different authors as an appropriate way to try to improve the safety of medium and small fishing vessels, by providing the crews with simple and easy to understand stability related information. These systems, which have to be easy to use, to understand and inexpensive to install and maintain, are normally based on simplified diagrams and colour codes. Then, from a series of simplified loading conditions, an estimation of the risk level of the vessel in a given situation is provided.

Some examples include the Womack matrix (Womack, 2003), the Wolfson stability guidance (Scarponi, 2017) or the approaches from the Norwegian Maritime Directorate (Wolfson Unit, 2004) or CENTEC in 2010 (Rodrigues et al., 2012). Other alternatives, such as the one from the Icelandic Administration (Viggosson, 2009), are not strictly speaking guidance systems, but could be included within the methods aimed at reducing stability-related accidents in fishing vessels.

Although the performance of some of these approaches has shown to be very good, as the Icelandic case, most of the aforementioned systems still rely on the subjective appreciation of the crew, and also have the drawback of losing simplicity as the size of the vessel increases, thus minimizing their performance.

The analysis of roll motion in real time to determine the stability characteristics of the vessel in real time, together with some type of linked guidance system, has been stated by different authors as an alternative to overcoming the aforementioned issues. The first proposal by Koyama dates from the 1982 (Koyama, 1982), and it consisted on a pendulum that measured roll period, which was then processed by an onboard computer able to compute roll motion RMS and generate an alarm if necessary. In Köse et al. (1995), the authors propose an expert system fed by different sensors, including accelerometers, pressure transducers, radar and Loran-C, with the objective of avoiding capsizing, especially due to stability failures in waves.

More recently, Terada et al. (2016), propose an autoregressive procedure and a general state space modelling for estimating the vessel metacentric height (*GM*), testing the system with good results using both scale model tests and real sea trials of a containership, although the system was not tested in small vessels.

Following these approaches, the authors have been developing their own proposal (Santiago Caamaño et al., 2018a), with the objective of linking a simplified stability guidance system (Míguez González et al., 2012), with a methodology for estimating the vessel *GM* (Míguez González et al., 2017), and which could overcome the main drawbacks of the aforementioned proposals (need for crew interaction, complexity and accuracy of the obtained results).

In this work, a study of the performance of the aforementioned method for estimating the vessel metacentric height, will be presented. This method is based on the analysis of the roll motion spectrum, which is obtained through Fast Fourier Transform (FFT) of the vessel roll motion time series, on a sequential way.

In previous works (Míguez González et al., 2017), the authors have validated the accuracy of this methodology using roll motion data obtained from a nonlinear roll model, under the effect of irregular beam waves and gusty winds, obtaining promising results.

In order to evaluate how does the proposed system behave in a more realistic scenario, data from sea trials corresponding to a fishing campaign of a medium sized pair stern trawler, where stability data have been manually monitored on a continuous basis, will be used.

2. SIMPLIFIED STABILITY GUIDANCE SYSTEM

2.1 System overview

The proposed simplified stability guidance system is based on the one previously developed by the authors (SKIPPER, Míguez González et al. (2012)), and which had a major drawback, consisting on the need for crew interaction for determining the vessel stability level.

In order to try to solve this issue, an additional module has been added to the current version, which has the main objective of minimizing the need for manual input of data within the system. In this module, vessel metacentric height is obtained after the estimation of natural roll frequency (applying the methodology described in the next section). From it, an Stability Index (SI), computed by evaluating the mandatory vessel intact stability criteria (IMO, 2012), is determined. This SI is then used for displaying, using a colour bar, the stability level of the vessel to the crew in a simple and understandable way.

In Figure 1, an screenshot of this system is included. This new module is described more in detail in Santiago Caamaño et al. (2018a).

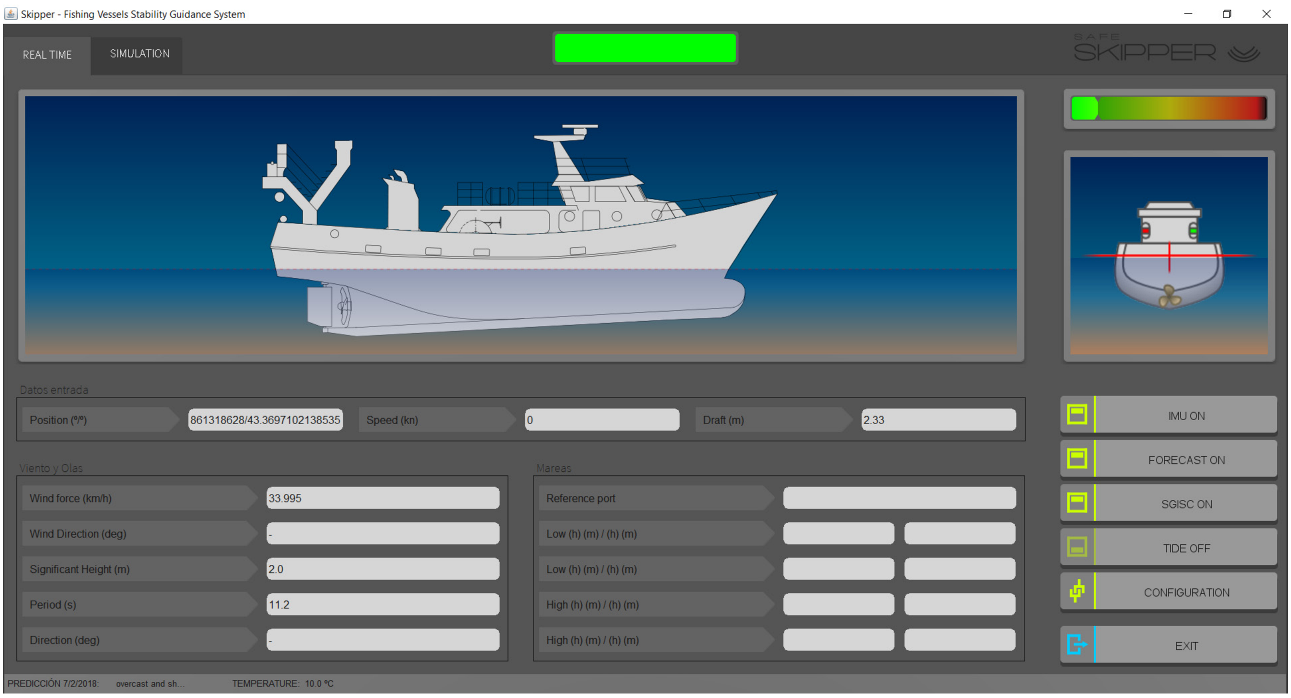

Figure 1. Simplified stability guidance system. Real time module.

2.2 Natural roll frequency estimation methodology

In order to estimate the natural roll frequency of the vessel in real time, a methodology based on the analysis of the vessel roll motion (Figure 2), which is described in detail in Míguez González et al. (2017), has been applied.

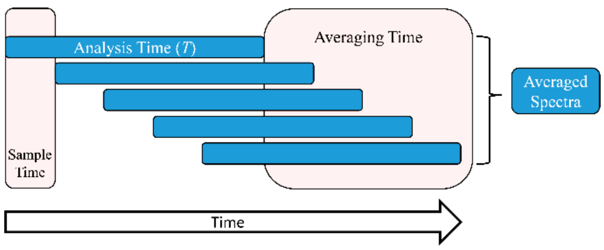

Figure 2. Proposed methodology Míguez González et al. (2017).

This method relies on the assumption that the peak frequency of the vessel roll spectrum coincides with its natural roll frequency. In order to set up a methodology for the real time analysis of this spectrum, and taking into consideration that subsequent spectra may differ from the previous or following ones, a sequential method has been proposed.

So, the resulting roll spectrum will be obtained after averaging, for a given time (known as "averaging time"), the roll spectra obtained by applying FFT for subsequent overlapped time segments of length "analysis time", obtained for a given "sample time".

After the averaging, and in order to increase the frequency resolution of the obtained spectrum (which only depends on the length of the time series under analysis, the "analysis time"), a smoothing process is done, applying a parametric model based on the superposition of three Gaussian functions.

Once these smoothed roll spectrum has been obtained and its peak frequency determined (which is assumed to coincide with the vessel natural roll frequency), the vessel metacentric height is estimated by applying the Weiss formula,

$$GM = \frac{{k_{xx}}^2 \omega_0^2}{g} \qquad (1)$$

where *GM* is the transversal metacentric height, k_{xx} the roll gyradius ($k_{xx} \approx 0.4 \cdot B$), ω_0 is the natural roll frequency, which coincides with the roll spectrum peak frequency, and g is the constant of gravity.

3. SEA TRIALS

In order to check the performance of the proposed methodology, a sea trial onboard a medium sized stern trawler, has been carried out. In order to do so, a complete fishing campaign has been monitored, including vessel motions, loading condition, heading and speed, and prevailing meteorological conditions, and these data have been used to test the proposed methodology for the estimation of vessel stability in real time.

The vessel under analysis is a medium sized pair stern trawler, which will be described in the following section, based in La Coruña port and which fishes on a daily basis together with her sistership in the coastal waters of Galicia, in Northwest Spain.

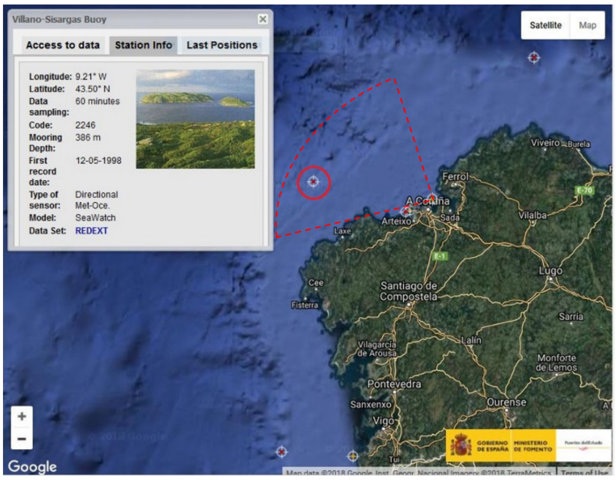

Figure 3. Sea trial area and SeaWatch buoy position.

The fishing ground in this case was in the vicinity of the Villano – Sisargas SeaWatch buoy, moored 35 miles off La Coruña port. Fishing area is highlighted with the red dashed line in Figure 3, while the red circle shows the buoy position.

Vessel motions have been measured by using an Xsense IMU, while speed, heading and route/location were obtained by using GPS. Regarding prevailing wave and wind conditions, hourly data from Villano-Sisargas buoy have been provided by Puertos del Estado, including, among others, significant wave height, peak period and mean wave direction, and mean wind speed and direction.

3.1 Test vessel

The vessel under analysis is a pair stern trawler, very similar to the one analysed in Míguez González et al. (2017), where the natural roll frequency estimation methodology was tested using roll motion data from a 1 degree of freedom nonlinear mathematical model. The main characteristics of the ship are included in Table 1. Its hull sections, together with an image of the vessel, are shown in Figure 4 and 5.


Figure 4. Test vessel. Photo courtesy of José R. Montero.

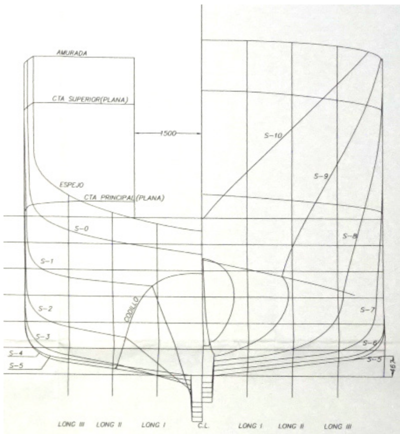
Figure 5. Test vessel: hull sections.

Table 1. Test vessel: main characteristics.

Overall Length	30.70 m
Length Between Perpendiculars	25.20 m
Beam	8.00 m
Depth	3.60 m
Design Draft	3.55 m
Displacement	504 t

3.2 Trial conditions

The whole fishing campaign lasted for a total of 19 hours, including 3 hours of sailing to the fishing ground, 10 hours of fishing and 6 hours of sailing back to port. In order to have a comparative value to check the performance of the natural roll frequency estimation methodology, the loading condition of the vessel during the whole campaign has been manually monitored, including tank filling levels, approximate fish weight and location, situation and weight of fishing nets and other equipment and number of people onboard. Ship lightweight has been obtained from the vessel compulsory inclining experiment, included in the stability booklet. In this work, a roll time series corresponding to 2h 5' has been analysed to test the proposed methodology. This situation corresponds to a condition with no fish in holds, with the vessel trawling together with her sistership at reduced speed, in slight starboard beam to quartering forward seas and lateral port wind, with a 67 % of fuel remaining and a 100 % of the rest of the consumables.

Table 2. Test series parameters.

Mean Draft	3.225 m
Trim	1.750 m
Displacement	469 t
Metacentric Height (*GM*)	0.385 m
Roll Gyradius ($k_{xx} = 0.4 \cdot B$)	3.2 m
Natural Roll Frequency (ω_0)	0.607 rad/s
Natural Roll Period	10.35 s
Average Heading	247º
Mean Vessel Speed	1.72 knt
Mean Significant Wave Height	0.9 m
Mean Wave Peak Period	10.25 s
Mean Wave Direction	322.5º
Mean Wind Speed	1.29 m/s
Mean Wind Direction	154º

In Table 2, vessel conditions during this period, together with mean wind and wave data, are presented. Natural roll frequency has been obtained by applying the Weiss formula using the vessel metacentric height estimated for this loading condition and the roll gyradius.

3.3 Natural roll frequency estimation results

The roll motion of the vessel during these 2h 5' is reported in Figure 7. As it can be appreciated in this figure, and due to the slight values of wind and waves, maximum roll amplitude does not reach large values.

In addition to this, and near the time instant 3000 s, it can be observed a change in the vessel heel angle, which goes from around 1 degree to starboard side to 0.5 degrees to port side. This fact is explained due to a modification of the two trawling vessels heading, which lead to a slight reduction of the net tension. Considering that the vessel under analysis is the one trawling at the port side of the couple (Figure 6), and that it had an initial heel angle of 2.5 degrees to port while not fishing, the reduction of the net tension reduced the heeling to the starboard side induced by the net.

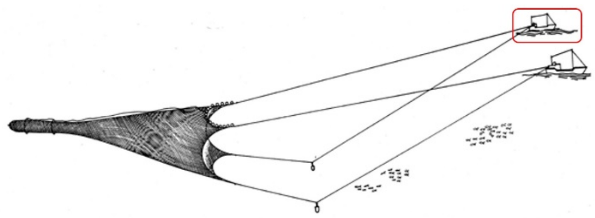

Figure 6. Pair trawling (FAO, 2008). Situation of the test vessel is highlighted.

In order to estimate the natural roll, frequency of the vessel, the already presented methodology has been applied to this roll motion time series. Considering the similarities between the ship studied in Míguez González et al. (2017) and the one tackled in this case, the same parameters have been used.

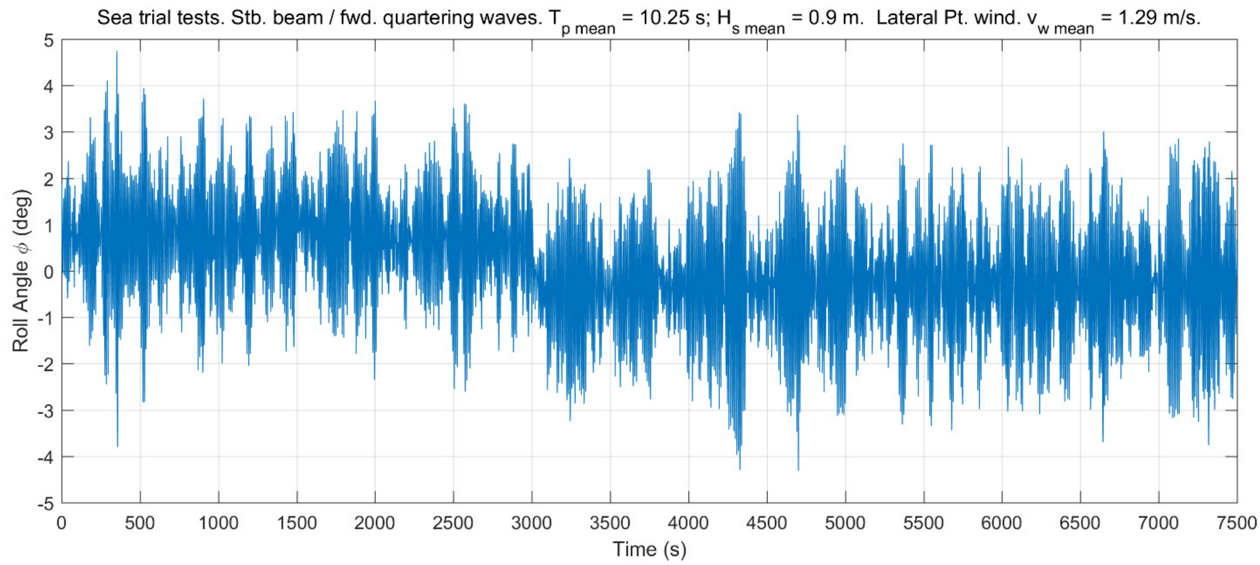

Figure 7. Analysed roll motion time series.

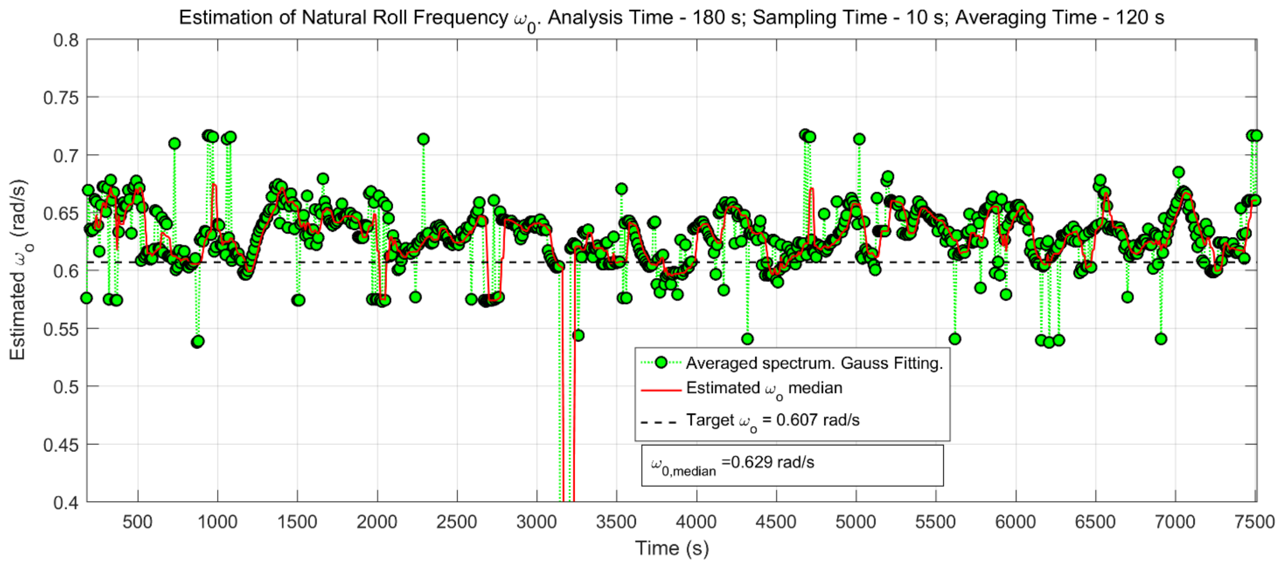

Figure 8. Natural roll frequency estimation results.

The “analysis time”, which has to provide a minimum resolution for the method and also has to be small enough as to detect possible changes in the loading condition, has been taken as 180 seconds. A “sample time” (determined by the possible modifications of the natural roll frequency) of 10 seconds has been selected. And finally, the “averaging time”, which represents the “memory” of the system, and which has to be long enough as to not being affected by short term estimations, but while trying not to hide changes in the loading condition, has been taken as 120 seconds.

The obtained results are shown in Table 3 and Figure 8, where green dots represent the natural roll frequency estimations at each analysis step, the red line represents the median of the last six estimations and the dashed black line is the manually computed target value for the natural roll frequency.

If the loading condition is considered to be constant during the whole time series, and the median of the estimations is taken as the representative value, a final estimated natural roll frequency of $\omega_{0\,est} = 0.629$ rad/s has been obtained, which is equivalent to an estimated metacentric height of $GM_{est} = 0.413$ m. This results in a deviation from the manually computed value of less than an 8 %, as shown in Table 3. If 5 % percentile and 95 % percentile are taken into account to study the deviation of the estimations from the target value along the whole time series, ω_0 deviations are within the range [-5.1 %, +9.89 %], and subsequent *GM* deviations are within the range [-9.95 %, +20.76 %].

Table 3. Estimation results.

Target Natural Roll Frequency	0.607 rad/s
Target Metacentric Height	0.385 m
Estimated ω_0 Median ($\omega_{0\ est}$)	0.629 rad/s
Estimated *GM* from $\omega_{0\ est}$ (GM_{est})	0.413 m
5 % Percentile Estimated ω_0 ($\omega_{0\ est\ 5\%}$)	0.576 rad/s
95 % Percentile Estimated ω_0 ($\omega_{0\ est\ 95\%}$)	0.667 rad/s
Estimated *GM* from $\omega_{0\ est\ 5\%}$ ($GM_{est\ 5\%}$)	0.346 m
Estimated *GM* from $\omega_{0\ est\ 95\%}$ ($GM_{est\ 95\%}$)	0.464 m

From these results, it can be observed that underpredictions in *GM* are kept under a reasonable value (a 10 %). However, for the case under analysis, the system has a tendency to overpredicting the vessel *GM*, while still keeping the 95 % of the estimations under a 20 % from the target value. This same situation has been already observed in the results obtained in Míguez González et al. (2017) for the mathematical model, where *GM* deviations where in the range of [-9.10 %, +17.80 %]. Although including a safety margin over the prediction is always a possible solution if this deviation is kept constant in all possible environments, the analysis of the whole fishing campaign, together with carrying out some more tests in more severe weather conditions, are necessary to accurately determine the deviation range and then to set up this safety increment.

In fact, the need of testing in more severe weather conditions is also necessary to accurately determine the source of the observed error, especially the influence of external excitations on the estimated roll spectra. In the case under analysis and due to the near absence of waves and wind, the obtained roll spectra are not heavily influenced by external excitations, and the main error source should then come from the use of the Weiss formula for the estimation of roll inertia (Santiago Caamaño et al., 2018b).

Another conclusion from the analysis of the obtained data, is that the effect of nets while fishing don´t seem to have a clear influence on the predictions, and that the methodology works reasonably well, even while trawling, at least under the wind and wave conditions present at the time of the study.

Finally, as it can be observed in Figure 8 near the time instant 3000 s, and coinciding with the moment where the vessel heading is changed, the obtained estimations are very far from the target value. This fact is possibly due to the effect of rudder forces acting during that period, which largely modify the rolling pattern of the vessel. However, taking into consideration that this type of manoeuvres are usually short time ones, the use of an outlier detection algorithm could be applied to remove these points from the data fed into the guidance system, avoiding the generation of false alarms.

4. CONCLUSIONS

In this paper, the performance of a methodology for the estimation of the vessel metacentric height in real time while in operation, based on the computation of the roll motion spectrum and, from it, on the estimation of the vessel natural roll frequency, has been tested in a real environment.

In order to do so, the authors have monitored a fishing campaign of a medium sized pair stern trawler, in waters off the port of A Coruña, Spain, obtaining all the relevant data regarding the motions, route, speed, loading condition and prevailing sea state and wind during the whole length of this campaign.

The roll motion time series of 2h 5’ corresponding to a trawling manoeuvre have been used, in this paper, to analyse the performance of the aforementioned methodology for making estimations of the vessel initial stability parameters (*GM*), showing good results, even under the effect of fishing nets.

However, obtained estimations are generally over predicting the desired target value, which could lead to the undesirable effect of overestimating the vessel stability. This fact is still an open issue.

Although the use of a safety margin could be a possible solution, it is necessary to analyse the behaviour of the system in a more severe sea state, in order to analyse whether these differences remain constant or increase when external excitations become more relevant.

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